Magnetic Domain Mapping of Buried Magnetic Structures

Magnetic domain orientation in a buried magnetic layer has been mapped as a function of external field in magnetic structures using x-ray magnetic circular dichroism and a small x-ray focal spot. This unique magnetic microscopy capability addresses magnetic behavior of buried layers in relation to the magnetic structure of the sample.

Composites of soft and hard magnetic materials have shown a great deal of promise as new high-strength permanent magnets. In these composites, the soft magnet provides a high magnetic saturation, whereas the magnetically hard material provides a high coercive field. Bilayers can be used as model systems to investigate the magnetization-reversal process in these composites [1]. In such bilayers, the hard magnetic material is grown epitaxially on a substrate to provide a well-defined magnetization axis, and the soft material is overlaid on top of it. Studies of the spatial magnetic structure in such bilayers, however, have been limited to measurements of the domains in the top, soft layer [2]. This limitation arises because the magnetic structure of the buried hard layer is inaccessible to established methods such as magnetic force microscopy or the magneto-optical Kerr effect, since these techniques are highly surface-sensitive. Thus, the structure of the buried layer upon magnetization reversal could not be studied directly using these methods. In this experiment, we have used a polarized x-ray microbeam [3] to overcome the limitations of the more conventional techniques. By using ~5-to-12-keV x-rays we can penetrate the top layers of the structure and thus measure the magnetic domain structure of the buried layer while an external field is applied.

The experiment was performed at the 4-ID insertion device beamline of the SRI-CAT. The polarized x-ray microbeam setup consists of two parts. First, phase-retarding optics are used to convert the linearly polarized beam from the undulator into a circularly polarized one, and second, a focusing setup is used to produce a micron-sized beam. The phase-retarding optics consist of a 400-μm-thick diamond (111) diffracting at 45° Using the beam transmitted through the diamond and deviating the diamond to either side of the exact Bragg condition, an x-ray beam of either right- or left-helicity ($P_c > 98\%$) can be obtained. Two different setups were used to focus the beam: Fresnel zone plates that produced a beam size of 3×5 μm^2 (vert. × horiz.), with ~10^8 photons/s in the focal spot; and a Kirkpatrick-Baez (KB) mirror that yielded a focal spot of 9×22 μm^2, with ~10^{10} photons/s.

X-ray magnetic circular dichroism (XMCD) was used to provide a contrast mechanism sensitive to the orientation of the magnetization. XMCD measures the dependence of the x-ray absorption on the angle between the helicity of incident circularly polarized photons and the magnetization of the sample. Therefore, the relative orientation of the local magnetic moments can be measured by taking the flipping ratio $\{(I^+ - I^-)/(I^+ + I^-)\}$ of the observed intensities for opposite helicities.

The sample studied was a 200 Å Fe/1600 Å SmCo/200 Å Fe/200 Å Ag layer grown on a MgO substrate. The SmCo was nominally deposited in the Sm_2Co_7 phase, although there are local deviations from the ideal stoichiometry, leading to $SmCo_5$ or $SmCo_3$ phases. Since the sample was grown on a relatively thick substrate, we used the fluorescence yield from the sample to measure the absorption. The fluorescence from the sample is proportional to the x-ray absorption and therefore is also sensitive to the XMCD signal. Measurements were performed at the Sm L_3 edge, monitoring the L_α fluorescence intensity. First, XMCD spectra were taken as a function of energy with an unfocused beam and the sample fully aligned. The best magnetic contrast was found to be at 6.710 keV, which was the energy then used to obtain all the magnetic structure images. Magnetic domain images were recorded as a function of the externally applied magnetic field. The sample was scanned in two dimensions through the microfocused beam. A magnetic field of up to 8 kG was applied parallel to the axis of easy magnetization.

Figure 1 shows a series of 250 × 500 μm² (vert. × horiz.) images taken with the KB mirror focusing setup for different applied magnetic fields. The relative position of each image along the sample magnetization curve is also indicated. The colors in the images correspond to the measured flipping ratios given by the scale on the right. A red color denotes a region where the local magnetization is antiparallel to the incoming beam, and a blue color indicates where it is oriented parallel.

The images in Fig. 1 clearly show the magnetic reversal of the domains in the SmCo layer upon

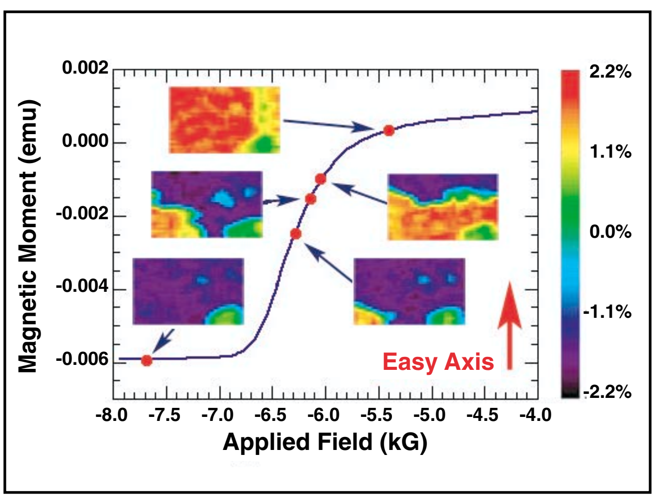

FIG.1. Images of the domain structure in Fe/SmCo with the corresponding positions on the magnetization curve.

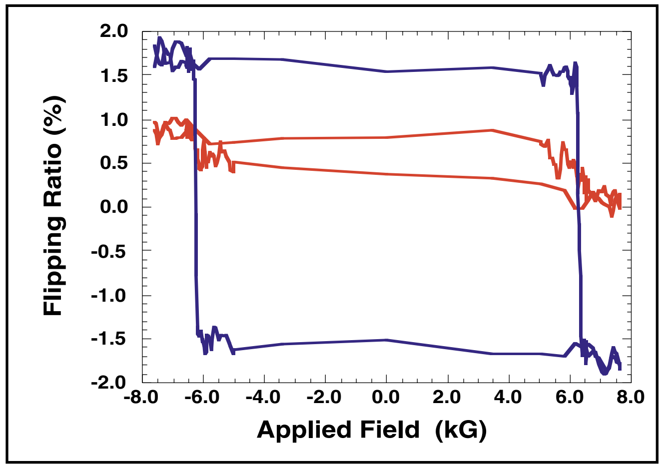

FIG. 2. Hysteresis measurements for the low-contrast region (red) and rest of sample (blue).

increase of the applied field. Visible at the top of the image is a large region (>500 μm) that nucleates at the top of the image and grows at the expense of the oppositely oriented domain. The boundary between the two domains is predominantly oriented perpendicular to the direction of magnetization. The direction of the domain wall can be understood from the chemical structure of the SmCo layer. The axis of easy magnetization in SmCo films is given by the c axis of the Sm_2Co_7 unit cell [4]. Stacking disorders induced by the $SmCo_5$ or $SmCo_3$ phases mentioned earlier will be oriented perpendicular to the easy axis. These stacking disorders may effectively pin the domain walls.

One interesting feature is found at the lower right portion of each image. In this region, very little magnetic contrast was observed for any applied field. To investigate this further, we performed local hysteresis measurements (shown in Fig. 2) at the center of this region and at a point where we observed clear domain formation. Figure 2 shows that, although the contrast is much smaller than that from the other parts of the sample, there is some change in this region also. We believe that the much smaller signal is due to either a local Co deficiency in this region or a misorientation of the epitaxial growth resulting in a crystal grain whose easy axis is oriented nearly perpendicular to the x-ray beam.

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